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For: SIGNAL PROCESSING METHOD, AND PULSE PHOTOMETER USING THE METHOD

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Sir,

I, Mitsuhiro Tsuchiya, hereby declare that I am conversant with both English and Japanese languages, and certify to best of my knowledge and belief that the attached is a true and correct English translation of Japanese Patent Application No. 2002-318278 filed October 31, 2002.

Mitsuhiro Tsuchiya

Date: December 13, 2006

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This is to certify that the annexed is a true copy of the following application as filed with this Office.

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[Title of the Invention] Pulse Photometer

[Claims]

[Claim 1]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals; and

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving means with a rotating matrix which rotates data by a prescribed angle.

[Claim 2]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

a light receiving member for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving member with a rotating matrix which rotates data by a prescribed angle; and

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the

waveform obtaining means to a frequency analysis.

[Claim 3]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

rotating angle determining means for determining a rotating angle of a rotating matrix for processing pulse wave data of the respective wavelengths obtained by the light receiving means in order to eliminate noise from the pulse wave data; and

waveform obtaining means for obtaining a waveform by processing the pulse wave data with the rotating matrix of the rotating angle which is determined by the rotating angle determining means.

[Claim 4]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

rotating angle determining means for determining a rotating angle of a rotating matrix for processing pulse wave data of the respective wavelengths obtained by the light receiving means in order to eliminate noise from the pulse

wave data; and

waveform obtaining means for obtaining a waveform by processing the pulse wave data with the rotating matrix of the rotating angle which is determined by the rotating angle determining means; and

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the waveform obtaining means to a frequency analysis.

[Claim 5]

The pulse photometer as set forth in any one of claims 1 to 4, characterized in that the rotating angle of the rotating matrix is such an angle that a distribution range projected on one of a horizontal axis and a vertical axis is minimized by rotating a graph plotted on a two-dimensional orthogonal coordinate system in which magnitudes of the respective wavelengths of pulse waves are taken as the axes.

[Claim 6]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

a light receiving member for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

norm rate calculating means for calculating norm values from the respective wavelengths of pulse wave data obtained by the light receiving member, and for calculating a rate of the norm values; and

light-absorbing-material-in-blood concentration calculating means for

calculating a concentration of a light-absorbing material in blood based on the norm rate calculated by the norm rate calculating means.

[Claim 7]

A pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving means with a rotating matrix which rotates data by a prescribed angle;

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the waveform obtaining means to a frequency analysis;

norm rate calculating means for calculating norm values from the respective wavelengths of pulse wave data obtained by the light receiving member, and for calculating a rate of the norm values; and

light-absorbing-material-in-blood concentration calculating means for calculating a concentration of a light-absorbing material in blood based on the norm rate calculated by the norm rate calculating means.

[Claim 8]

The pulse photometer as set forth in claim 6 or 7, characterized in that the light-absorbing-material-in-blood concentration calculating means calculates at least one of the concentration of the light-absorbing material is at

least one of an oxygen saturation in arterial blood, a concentration of abnormal hemoglobin in arterial blood, and a concentration of injected dye in arterial blood.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to an improvement in measurement for a concentration of a light-absorbing material in blood and a pulse rate performed by a pulse photometer used in the medical field, especially in diagnosis of a circulatory organ.

[0002]

[Conventional Art]

Known pulse photometers used in the medical field include an apparatus called a photoplethysmograph, which measures a pattern of a pulse wave and a pulse rate; an oxygen saturation SpO_2 measurement apparatus for measuring the concentration of a light-absorbing material included in the blood; an apparatus for measuring the concentration of methemoglobin, such as carboxyhemoglobin or Met hemoglobin; and an apparatus for measuring the concentration of injected pigment.

Among them, the apparatus for measuring oxygen saturation SpO_2 is particularly called a pulse oximeter.

[0003]

The principle of the pulse photometer is to determine the concentration of a substance of interest from a pulse wave data signal, wherein the data signal is obtained by causing light rays—which exhibit

different light absorbances against the substance of interest and have a plurality of wavelengths~~—~~to pass through a living tissue, and by consecutively measuring the quantity of transmitted light.

The applicant has already proposed in Japanese Patent No. 3270917 (Patent Document 1) a method of determining oxygen saturation in arterial blood or the concentration of a light-absorbing material. Namely, a living tissue is exposed to light rays having two different wavelengths, and two pulse wave signals are obtained from the resultant transmitted light. A graph is formed by plotting the magnitudes of the pulse wave signals on the vertical and horizontal axes, to thereby determine a regression line. The oxygen saturation in arterial blood or the concentration of light-absorbing material is determined from the slope of the regression line.

According to the invention, the accuracy of measurement is improved, and power consumption is reduced.

However, much computing operation is required to determine a regression line and the slope thereof through use of numerous sampled data sets pertaining to pulse wave signals of wavelengths.

[0004]

[Patent Document 1] Japanese Patent No. 3270917 (see Claims 1 and 2; Figs. 2 and 4)

[0005]

[Object to be Achieved by the Invention]

[0007]

It is an object of the invention to alleviate computing load and to accurately determine the concentration of a substance of interest even when

noise stemming from body motion has arisen in a pulse wave signal.

It is also an object of the invention to remove noise from a pulse wave signal even noise stemming from body motion has arisen in the pulse wave signal, thereby determining a pulse rate accurately.

[0006]

[How to Achieve the Object]

In order to achieve the above objects, according to the invention, there is provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals; and

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving means with a rotating matrix which rotates data by a prescribed angle (claim 1).

With this configuration, it is possible to easily obtain a waveform in which noise has been eliminated by processing the pulse wave data with the rotating matrix.

[0007]

According to the invention, there is also provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

a light receiving member for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving member with a rotating matrix which rotates data by a prescribed angle; and

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the waveform obtaining means to a frequency analysis (claim 2).

With this configuration, it is possible to easily obtain a waveform in which noise has been eliminated by processing the pulse wave data with the rotating matrix, and to accurately obtain the fundamental frequency of the pulse wave or the pulse rate based on the waveform.

[0008]

According to the invention, there is also provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

rotating angle determining means for determining a rotating angle of a rotating matrix for processing pulse wave data of the respective wavelengths obtained by the light receiving means in order to eliminate noise from the pulse wave data; and

waveform obtaining means for obtaining a waveform by processing the pulse wave data with the rotating matrix of the rotating angle which is determined by the rotating angle determining means (claim 3).

With this configuration, it is possible to determine a rotating angle proper for eliminating the noise from the pulse wave data with the rotating matrix, and to obtain a waveform in which the noise has been eliminated by processing with the rotating matrix of the determined rotating angle.

[0009]

According to the invention, there is also provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

rotating angle determining means for determining a rotating angle of a rotating matrix for processing pulse wave data of the respective wavelengths obtained by the light receiving means in order to eliminate noise from the pulse wave data; and

waveform obtaining means for obtaining a waveform by processing the pulse wave data with the rotating matrix of the rotating angle which is determined by the rotating angle determining means; and

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the waveform obtaining means to a frequency analysis (claim 4).

With this configuration, it is possible to determine a rotating angle proper for eliminating the noise from the pulse wave data with the rotating matrix; to obtain a waveform in which the noise has been eliminated by processing with the rotating matrix of the determined rotating angle; and to accurately obtain the fundamental frequency of the pulse wave or the pulse rate based on the waveform.

[0010]

The pulse photometer of the invention is characterized in that the rotating angle of the rotating matrix is such an angle that a distribution range projected on one of a horizontal axis and a vertical axis is minimized by rotating a graph plotted on a two-dimensional orthogonal coordinate system in which magnitudes of the respective wavelengths of pulse waves are taken as the axes (claim 5).

With this configuration, it is possible to eliminate the noise as much as possible by processing the pulse wave data with the rotating matrix.

[0011]

According to the invention, there is also provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

a light receiving member for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

norm rate calculating means for calculating norm values from the respective wavelengths of pulse wave data obtained by the light receiving

member, and for calculating a rate of the norm values; and

light-absorbing-material-in-blood concentration calculating means for calculating a concentration of a light-absorbing material in blood based on the norm rate calculated by the norm rate calculating means (claim 6).

With this configuration, it is possible to accurately calculate a concentration of a light-absorbing material in blood based on the norm rate obtained from the pulse wave data of the respective wavelengths.

[0012]

According to the invention, there is also provided a pulse photometer, characterized by comprising:

light emitting means for irradiating a living tissue with two different wavelengths of light;

light receiving means for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals;

waveform obtaining means for obtaining a waveform by processing pulse wave data of the respective wavelengths obtained by the light receiving means with a rotating matrix which rotates data by a prescribed angle;

waveform analyzing means for obtaining a fundamental frequency of a pulse wave or a pulse rate by subjecting the waveform obtained by the waveform obtaining means to a frequency analysis;

norm rate calculating means for calculating norm values from the respective wavelengths of pulse wave data obtained by the light receiving member, and for calculating a rate of the norm values; and

light-absorbing-material-in-blood concentration calculating means for

calculating a concentration of a light-absorbing material in blood based on the norm rate calculated by the norm rate calculating means (claim 7).

[0013]

The pulse photometer of the invention is characterized in that the light-absorbing-material-in-blood concentration calculating means calculates at least one of the concentration of the light-absorbing material is at least one of an oxygen saturation in arterial blood, a concentration of abnormal hemoglobin in arterial blood, and a concentration of injected dye in arterial blood (claim 8).

With this configuration, it is possible to accurately obtain the fundamental frequency of the pulse wave or the pulse rate from a waveform in which the noise has been eliminated by processing the pulse wave data with the rotating matrix, and to accurately calculate a concentration of a light-absorbing material in blood based on the norm rate obtained from the pulse wave data of the respective wavelengths.

[0014]

[Embodiments of the Invention]

On the occasion of explanation of an embodiment of the invention, the principle of the invention will be described by means of taking, as an example, a pulse oximeter for measuring oxygen saturation in arterial blood.

The technique of the invention is not limited to a pulse oximeter, but can also be applied to an apparatus (pulse photometry) which measures methemoglobin (carboxyhemoglobin, Met hemoglobin, etc.) and light-absorbing materials in blood, such as pigment injected into blood, through use of the principle of pulse photometry.

[0015]

The configuration of a pulse oximeter which measures oxygen saturation in arterial blood is shown in Fig. 1, which is a schematic structural block diagram.

Light-emitting elements 1, 2, which emit light rays of different wavelengths, are activated by means of a drive circuit 3 so as to emit light alternately.

The light adopted for the light-emitting elements 1, 2 may be embodied by an infrared ray (having a wavelength of, e.g., 940 nm) which exerts less influence on oxygen saturation in arterial blood, or an infrared ray (having a wavelength of, e.g., 660 nm) which exhibits high sensitivity against a change in oxygen saturation in arterial blood.

[0016]

The light emitted from the light-emitting elements 1, 2 passes through living tissue 4 and is received by a photodiode 5 and converted into an electric signal.

Reflected light may be received.

The thus-converted signal is amplified by an amplifier 6 and divided into corresponding filters 8-1, 8-2 assigned to respective light wavelengths by means of a multiplexer 7.

The signals assigned to the filters are filtered through the filters 8-1, 8-2, whereby noise components are diminished and digitized by means of an analog-to-digital converter 9.

[0017]

The digitized signal sequences corresponding to an infrared ray and red light form respective pulse wave signals.

The digitized signal sequences are input to a processing section 10 and processed in accordance with a program stored in ROM 12. Oxygen saturation SpO_2 is measured, and a result of measurement is displayed on a display section 11.

[0018]

<Reduction in noise by means of rotating matrix and Calculation of fundamental frequency of pulse wave>

Next will be described calculation processing for reducing noise in two pulse wave data signals of wavelengths digitized by an analog-to-digital converter 9 through use of a rotating matrix.

Fig. 2 shows pulse waves corresponding to the infrared light and the red light and measured over a period of eight seconds, wherein noise stemming from the body motion is superposed.

The horizontal axis represents time, and the vertical axis represents amplitudes of the pulse waves.

For the convenience, in the horizontal axis, a mean value of the data pertaining to the eight-second period is set to zero.

However, calculation can be effected without carrying out processing for setting a mean value to zero.

[0019]

Fig. 3 is a graph in which the horizontal axis represents the amplitude of the pulse wave for the infrared light and the vertical axis represents the amplitude of the pulse wave for the red light. The graph is based on the data measured at the same time among the pulse wave data shown in Fig. 2.

An infrared ray and red light are illuminated alternately. Hence,

strictly speaking, they are not emitted simultaneously. However, a value of a received infrared ray and a value of received red light, being chronologically adjacent to each other, are taken as if they were obtained at the same time, thereby obtaining the graph of Fig. 3.

A ratio of pulsation components to d.c. components of a pulse wave is determined, to thereby approximate pulsation components of light absorbance attributable to pulsation.

Transition in the graph shown in Fig. 3 does not assume an angle of 45°. The reasons for this are that a difference exists between the amplitude of pulsation components of the infrared ray pulse wave and the amplitude of pulsation components of the red light pulse wave, and that noise is superimposed on the pulsation components.

[0020]

The pulse wave data are subjected to rotational calculation through use of a rotating matrix.

A data sequence pertaining to a ratio of pulsation components to DC components of the infrared light pulse wave; i.e., IR, is expressed as follows.

[0021]

[Equation 1]

$$IR = \{IR(ti) : ti = 0,1,2,3,\cdots\} \qquad (1)$$

[0022]

A data sequence pertaining to a ratio of pulsation components to DC components of the red light pulse wave; i.e., R, is expressed as follows.

[0023]

[Equation 2]

$$R = \{R(ti) : ti = 0,1,2,3,\cdots\} \quad (2)$$

[0024]

Data pertaining to IR and R, both being obtained at the same time ti, are defined by a matrix in the following manner.

[0025]

[Equation 3]

$$S = \begin{pmatrix} IR(ti) \\ R(ti) \end{pmatrix} \quad (3)$$

[0026]

Provided that a rotating matrix for effecting rotation by the rotating angle θ [rad] is taken as A, A can be expressed as follows.

[0027]

[Equation 4]

$$A = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \quad (4\text{-}1)$$

[0028]

The following X is obtained by rotating the pulse wave data S by the rotating angle θ [rad] by the rotating matrix A.

[0029]

[Equation 5]

$$X \equiv \begin{pmatrix} X1(ti) \\ X2(ti) \end{pmatrix} = A \cdot S = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} IR(ti) \\ R(ti) \end{pmatrix} \quad (5)$$

[0030]

In addition to the rotating matrix A, another rotating matrix A' provided below may also be employed.

[0031]

$$A' = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \qquad (4\text{-}2)$$

[0032]

Here, Fig. 4 shows a graph plotted by rotating the pulse wave data S with the rotating angle θ being rotated from 0 to 9π/30 [rad] in increments of π/30 [rad].

As can be seen in Fig. 4, the pulse wave data S are rotated around a point of zero for the horizontal and vertical axes (i.e., a point where a mean value of the red light pulse wave and a mean value of the infrared light pulse wave are achieved). When θ is 9π/30 [rad], the range in which the data projected onto the horizontal axis (X1) are distributed is minimized, and the range in which the data projected onto the vertical axis (X2) are distributed is maximized.

When θ is rotated from 9π/30 [rad] by further π/2 [rad] up to 24π/30 [rad](= 12π/15 [rad]), the range in which the data projected onto the horizontal axis (X1) are distributed is obviously maximized, and the range in which the data projected onto the vertical axis (X2) are distributed is obviously minimized.

[0033]

There will now be described the kind of waveform obtained as a result of the pulse waveform data S being processed into X by the rotating matrix A achieved when θ is rotated to 9π/30 [rad] and 24π/30 [rad].

Fig. 5 shows a waveform of X obtained by processing the pulse wave data S shown in Fig. 2 through use of the rotating matrix A with the rotating

angle θ being taken as 9π/30 [rad].

X1(ti) at which the range projected on the horizontal axis has been minimized is computed by the following equation.

[0034]

[Equation 7]

$$X1(ti)[\theta = 9\pi/30] = \cos\theta \cdot IR(ti) - \sin\theta \cdot R(ti) \qquad (6)$$

[0035]

X2(ti) at which the range projected on the horizontal axis has been maximized is computed by the following equation.

[0036]

[Equation 8]

$$X2(ti)[\theta = 9\pi/30] = \sin\theta \cdot IR(ti) + \cos\theta \cdot R(ti) \qquad (7)$$

[0037]

Noise is understood to be reduced from the wave form of X1 shown in Fig. 5.

When the pulse wave data S are processed by the rotating matrix A with θ being taken as 24π/30 [rad], the waveform of X2 becomes another waveform from which noise has been reduced.

X1(ti) at which the range projected on the horizontal axis is maximized is computed by the following equation.

[0038]

[Equation 9]

$$X1(ti)[\theta = 24\pi/30] = \cos\theta \cdot IR(ti) - \sin\theta \cdot R(ti) \qquad (8)$$

[0039]

X2(ti) at which the range projected on the vertical axis is minimized is

computed by the following equation.

[0040]

[Equation 10]

$$X2(ti)[\theta = 24\pi / 30] = \sin\theta \cdot IR(ti) + \cos\theta \cdot R(ti) \qquad (9)$$

[0041]

Thus, the rotating angle θ is determined such that the range in which the data projected on the horizontal axis are distributed is minimized. Processing the pulse wave data S with the thus determined rotating angle, there can be obtained a principal component waveform of a pulse wave whose noise is suppressed.

[0042]

Next, calculation of the fundamental frequency of a pulse wave will be described.

Fig. 6 shows a pulse wave from which noise has not yet been removed and which is shown in Fig. 2, along with spectra obtained by frequency analysis of the waveform of pulse wave whose noise has been reduced by use of the rotating matrix.

The horizontal axis represents a frequency, and the vertical axis shows a spectrum.

In relation to a spectrum of a pulse wave obtained before noise is reduced (hereinafter called a "pre-rotational pulse wave signal"), a spectrum in a noise frequency range fn appears intensively, whereas a spectrum in the fundamental frequency fs of the pulse wave is essentially absent.

In relation to a spectrum obtained by frequency analysis of a waveform of pulse wave whose noise has been reduced through use of the

rotating matrix (hereinafter called a "post-pulse wave signal"), a spectrum in the fundamental frequency fs of the pulse wave is seen to intensively appear so as to be distinguishable from a spectrum in the noise frequency band fn. The fundamental frequency fs of the pulse wave can be determined.

If the fundamental frequency fs [Hz] of the pulse wave is determined, a pulse rate (fs x 60 [times/min.]) can be readily determined.

[0043]

As mentioned above, the waveform of pulse wave whose noise has been diminished can be obtained through use of a rotating matrix of predetermined angle. The fundamental frequency or pulse rate of the pulse wave can be determined.

Here, the predetermined angle may be determined beforehand or changed adaptively during a period of measurement.

[0044]

<Calculation of Oxygen Saturation>

Fig. 3 is a graph formed when the red light pulse wave data are plotted on the horizontal axis and the infrared ray pulse wave data are plotted on the vertical axis. The slope of the graph is determined through use of a norm ratio.

First, the L2 norm for the infrared pulse wave data IR is determined. Since an infrared light pulse wave data sequence is determined by Equation 1, the L2 norm can be expressed by the following equation.

[0045]

[Equation 11]

$$\|IR\| = \sqrt{\sum IR(ti)^2} \qquad (10)$$

[0046]

Next, the L2 norm of the red light pulse wave data R is determined. Since a red light pulse wave data sequence is determined by Equation 2, the L2 norm can be expressed by the following equation.

[0047]

[Equation 12]

$$\|R\| = \sqrt{(\sum R(ti)^2} \qquad (11)$$

[0048]

Here, provided that

[0049]

[Equation 13]

$$\Phi = \frac{\|R\|}{\|IR\|} \qquad (12),$$

[0050]

Φ correlates with the oxygen saturation SpO_2. Taking a function representing the correlation as “f,” the oxygen saturation will be expressed as follows.

[0051]

[Equation 14]

$$SpO_2 = f(\Phi) \qquad (13)$$

[0052]

Thus, the oxygen saturation SpO_2 can be determined.

Fig. 3 shows a line whose slope is determined by a norm ratio.

Here, the term “norm” refers to a mathematical concept. An Euclidean norm or a square norm maps onto a scalar the magnitude of a vector having “n” elements.

As mentioned above, the oxygen saturation SpO2 can be determined on the basis of a ratio of the L2 norm value (square norm) of the red light pulse wave data R over a predetermined period of time and the L2 norm value of the infrared ray pulse wave data over a predetermined period of time.

Here, the red light pulse wave data R and the infrared ray pulse wave data IR over a predetermined period of time may be used for a given period of time in reverse chronological order from the sequentially-obtained present pulse wave.

The L2 norm is used for the norm value, but another norm value determined by another computing method may also be used.

[0053]

(First Embodiment)

The apparatus using the foregoing principle will now be described by reference to a schematic block diagram and a processing flowchart.

The schematic block diagram is identical with that shown in Fig. 1 that has been described previously.

The light-emitting elements 1, 2 are activated by the drive circuit 3 so as to alternately effect emission, thereby emitting light rays of different wavelengths.

The light rays emitted from the light-emitting elements 1, 2 pass through the living tissue 4 and are then received by the light-receiving section (photodiode) 5, where the light is converted into an electric signal.

The thus-converted signals are amplified by the amplifier 6 and divided to the filters 8-1, 8-2 assigned to the respective light wavelengths, by means of the multiplexer 7.

The signals allocated to the respective filters are filtered by means of the filters 8-1, 8-2, whereby noise components of the signals are diminished. The signals are digitized by the analog-to-digital converter 9.

The digitized signal trains corresponding to the infrared ray and the red light form the pulse waves.

The digitized signal trains are input to the processing section 10 and processed by means of a program stored in the ROM 12, wherein a pulse rate PR and oxygen saturation SpO_2 are calculated. The resultant calculated value is displayed on the display section 11.

[0054]

Next, a processing flow to be used for computing the pulse rate PR and the oxygen saturation SpO_2 are described by reference to Fig. 7. Measurement is then initiated (step S1). The red light pulse wave and the infrared ray pulse wave are detected in the manner mentioned above (step S2). The digitized signal trains (respective pulse wave data sets) are acquired by the processing section 10.

In accordance with the program stored in the ROM 12, the processing section 10 processes the pulse wave data in the following manner by means of reading and writing data, which are being processed, from and to RAM 13.

[0055]

First, a pulsation component ratio of the infrared ray pulse wave to a d.c. component of the pulse wave and a pulsation component ratio of the red light pulse wave to a d.c. component of the pulse wave are determined (step S3).

Next, processing for determining the pulse rate PR (steps S4 to S6)

and processing for determining oxygen saturation SpO_2 (steps S7 to S9) are performed simultaneously.

[0056]

Through the processing for determining the pulse rate PR (steps S4 to S6), a waveform whose noise is reduced is obtained from the data S pertaining to the infrared ray pulse wave data IR and the red light pulse wave data R, according to Equation 5 by means of the rotating matrix A for which a rotational angle is set beforehand (step S4).

Here, a rotating angle to be set is an angle at which the area projected in an axial direction is minimized in the manner shown in Fig. 4, by means of rotating a graph in which the infrared ray pulse wave data IR are plotted on the horizontal axis and the red light pulse wave data R are plotted on the vertical axis such as those shown in Fig. 3.

The rotational angle may be, for example, $9\pi/30$ [rad] or $24\pi/30$ [rad].

The waveform whose noise has been reduced can be obtained from the data pertaining to an axial component which minimizes the projected area.

The waveform whose noise has been reduced is subjected to frequency analysis in such a manner as shown in Fig. 6, thereby determining the fundamental frequency of the pulse wave data (step S5).

The pulse rate fs is determined from the fundamental frequency according to fS x 60 [times/min] and displayed on the display section 11.

[0057]

During processing for determining oxygen saturation SpO2 (steps S7 to S9), L2 norms are determined from the infrared-ray pulse wave data IR and the red light pulse wave data R, both being obtained over a predetermined

period of time, by means of Equations (10) and (11). A ratio between the L2 norms is determined by Equation (12).

A ratio of the infrared ray pulse signal whose noise has been removed to the red light pulse signal whose noise has been removed is determined, to thus compute oxygen saturation (step S7).

The L2 norm ratio is taken as Φ, the oxygen saturation SpO_2 is determined according to Equation (12) (step S8), and the thus-obtained oxygen saturation is displayed on the display section 11 (step S9).

[0058]

When measurement is continued, processing returns to step S2, where processing is iterated. When measurement is not performed, measurement is completed (step S11).

[0059]

(Second Embodiment)

Next, another second embodiment will be described by reference to Fig. 8.

A difference between the first and second embodiments lies in that, in step S4, a rotational angle is not determined beforehand but is determined from obtained data. As shown in Fig. 8, processing is performed with step S4-1 being separated from step S4-2.

The other steps are the same as those of the first embodiment, and hence their repeated explanations are omitted.

[0060]

During processing (steps S4 to S6) for determining a pulse rate PR, a graph such as that shown in Fig. 3 is first plotted through use of the infrared

ray pulse wave data IR and the red light pulse wave data R, both being obtained over a given period of time.

A rotational angle at which the area projected in the axial direction is minimized is determined (step S4-1).

Pulse wave data of respective wavelengths are processed by means of a rotating matrix through an obtained rotational angle. A waveform whose noise has been reduced is obtained from data pertaining to axial components which minimize the projected area (step S4-2).

As mentioned above, the characteristic of the second embodiment lies in that the rotational angle of the rotating matrix is not a fixed angle and has an adaptive characteristic such that the rotational angle is changed, as necessary, according to detected pulse wave data.

[0061]

The foregoing descriptions have described the invention by means of taking, as an example, a pulse oximeter which measures oxygen saturation in arterial blood. The technique of the invention is not limited to a pulse oximeter and can also be applied to an apparatus (pulse photometry)—which measures methemoglobins (carboxyhemoglobin, Met hemoglobin, etc.) and light-absorbing materials in blood, such as pigment injected into blood, through use of the principle of pulse photometry—by means of selection of a wavelength of the light source.

In the invention, the amplitude of the pulse wave may be a peak value obtained in every pulsation or may be sampling data per se constituting the pulse wave.

In a case where the sampling data per se constituting the pulse wave

is used, data amount increases but it is not necessary to obtain the peak value.

[0062]

[Advantages of the Invention]

According to the pulse photometer set forth in claim 1, it is possible to easily obtain a waveform in which noise has been eliminated by processing the pulse wave data with the rotating matrix.

[0063]

According to the pulse photometer set forth in claim 2, it is possible to easily obtain a waveform in which noise has been eliminated by processing the pulse wave data with the rotating matrix, and to accurately obtain the fundamental frequency of the pulse wave or the pulse rate based on the waveform.

[0064]

According to the pulse photometer set forth in claim 3, it is possible to determine a rotating angle proper for eliminating the noise from the pulse wave data with the rotating matrix, and to obtain a waveform in which the noise has been eliminated by processing with the rotating matrix of the determined rotating angle.

[0065]

According to the pulse photometer set forth in claim 4, it is possible to determine a rotating angle proper for eliminating the noise from the pulse wave data with the rotating matrix; to obtain a waveform in which the noise has been eliminated by processing with the rotating matrix of the determined rotating angle; and to accurately obtain the fundamental frequency of the pulse wave or the pulse rate based on the waveform.

[0066]

According to the pulse photometer set forth in claim 5, it is possible to easily determine the rotating angle of the rotating matrix.

[0067]

According to the pulse photometer set forth in claim 6, it is possible to accurately calculate a concentration of a light-absorbing material in blood based on the norm rate obtained from the pulse wave data of the respective wavelengths.

[0068]

According to the pulse photometer set forth in claim 7, it is possible to at least one of a concentration of a light-absorbing material in blood based on the norm rate obtained from the pulse wave data of the respective wavelengths.

[0069]

According to the pulse photometer set forth in claim 8, it is possible to simultaneously perform, by the same apparatus, determination of the fundamental frequency of the pulse wave or the pulse rate from a waveform in which the noise has been eliminated by processing the pulse wave data with the rotating matrix, and calculation of at least one of a concentration of a light-absorbing material in blood based on the norm rate obtained from the pulse wave data of the respective wavelengths.

[Brief Description of the Drawings]

Fig. 1 is a block diagram showing a schematic configuration of pulse oximeter of the invention.

Fig. 2 is a graph showing detected pulse waves.

Fig. 3 is a graph in which the amplitude of a red light pulse wave is plotted on a horizontal axis and the amplitude of an infrared ray pulse wave is plotted on a vertical axis.

Fig. 4 is a view of the graph shown in Fig. 3 when rotated in increments of $\pi/30$ [rad].

Fig. 5 is a view showing the waveform of a pulse wave processed by a rotating matrix with a rotational angle of $9\pi/30$ [rad].

Fig. 6 is a view showing spectra of a waveform X1 shown in Fig. 5.

Fig. 7 is a flowchart showing a processing flow according to a first embodiment.

Fig. 8 is a flowchart showing a processing flow according to a second embodiment.

[Description of the Reference Numerals]

1	light emitting element
2	light emitting element
3	driving circuit
4	living tissue
5	photo diode
6	converter
7	multiplexer
8	filter
9	A/D converter
10	processing section
11	display section
12	ROM
13	RAM

[Designation of Document] Abstract

[Abstract]

[Object]

To provide a pulse photometer by which noise is removed from pulse wave data to precisely acquire pulse and concentration of an object substance even when noise is generated by body motion.

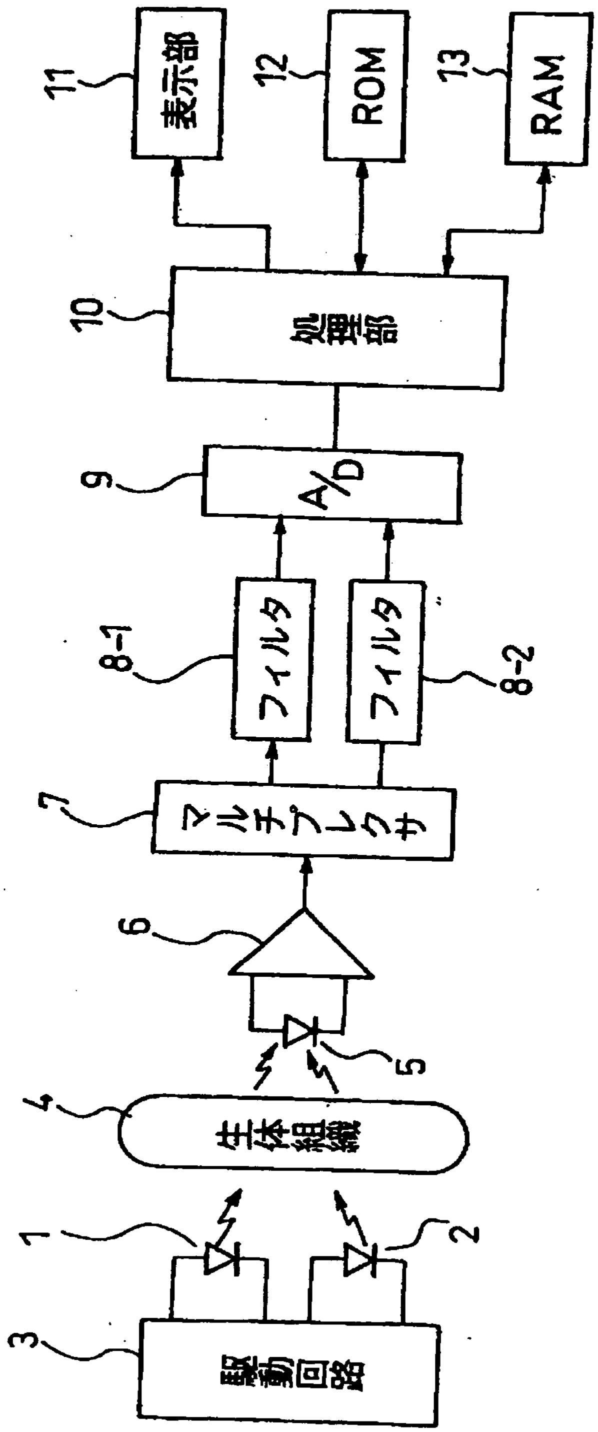
[How to Achieve the Object]

A pulse photometer comprises: light emitting means (1, 2) for irradiating a living tissue (4) with two different wavelengths of light alternately; light receiving means (5) for converting the respective wavelengths of light, which are emitted from the light emitting means and transmitted through or reflected from the living tissue, into electric signals; and a processing section (10) for processing the pulse wave data of the respective wavelengths obtained by the light receiving section. In the processing section (10), it is determined a rotating angle of a rotating matrix for processing pulse wave data; and a waveform in which noise has been reduced is obtained by processing the pulse wave data with the rotating matrix of the rotating angle. Further, a fundamental frequency of a pulse wave or a pulse rate is obtained by subjecting the obtained waveform. On the other hand, norm values is calculated from the respective wavelengths of pulse wave data, and a rate of the norm values is further calculated. A concentration of a light-absorbing material in blood is calculated based on the norm rate calculated. An oxygen saturation in arterial blood, a concentration of abnormal hemoglobin in arterial blood, and a concentration of injected dye in arterial blood as the light-absorbing material.

[Representative Drawing] Fig.7

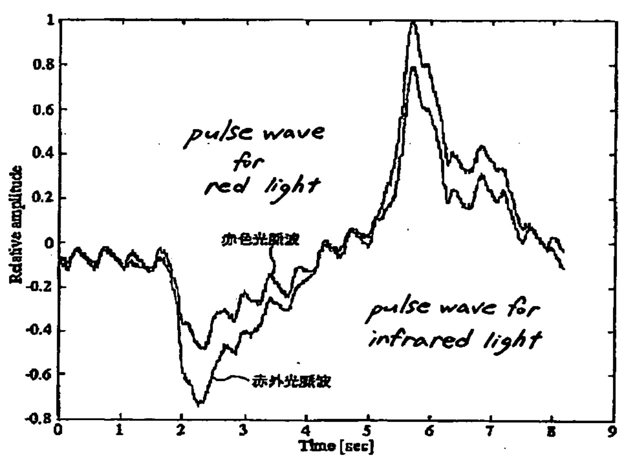
【書類名】　図面　*Designation of Document　Drawings*

【図１】　*Fig. 1*

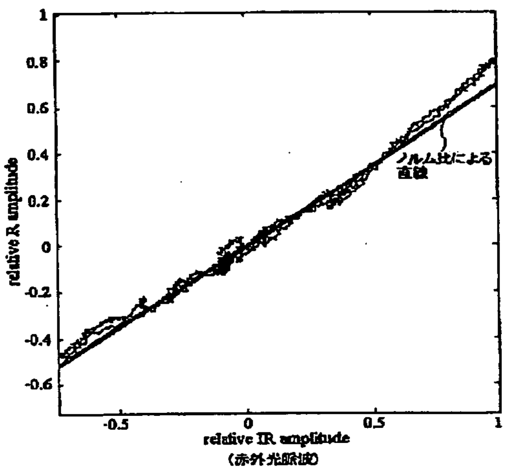


3: drive circuit
4: living tissue
7: multiplexer
8-1, 8-2: filter
9: A/D converter
10: processing section
11: display section

【図２】 *Fig. 2*


pulse wave for red light
赤色光脈波
pulse wave for infrared light
赤外光脈波
Relative amplitude
Time [sec]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
1
2
3
4
5
6
7
8
9

【図３】 Fig. 3

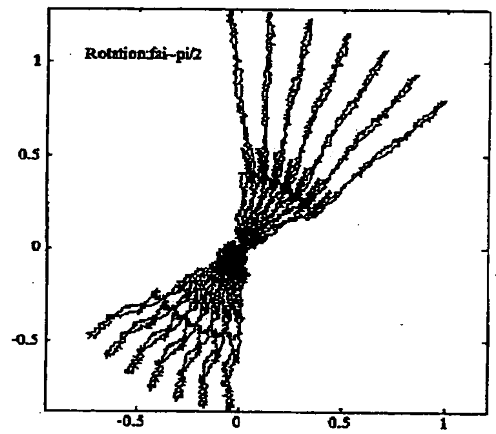


pulse wave for red light

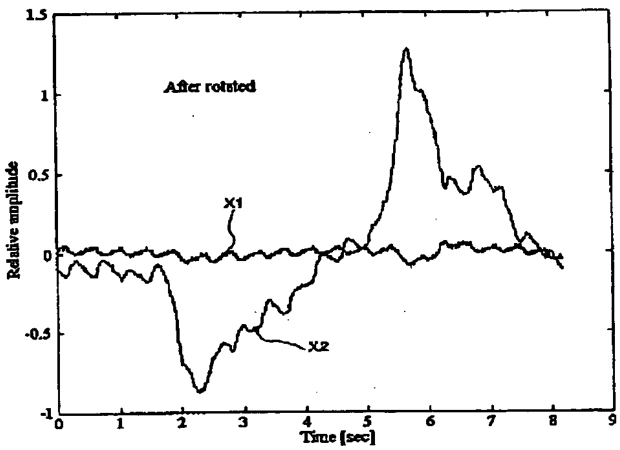
line corresponding to norm rate

pulse wave for infrared light

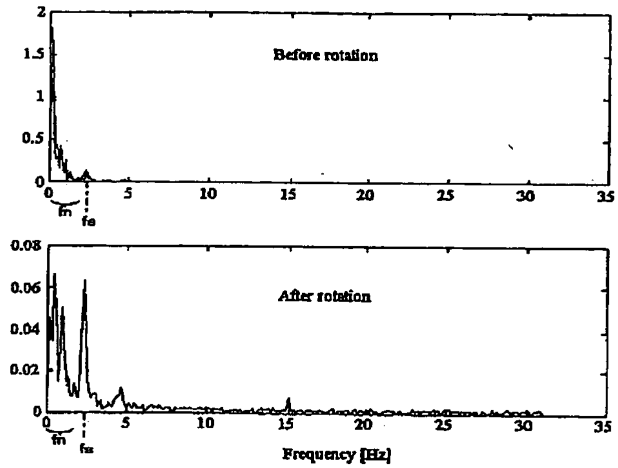
【図４】 Fig. 4



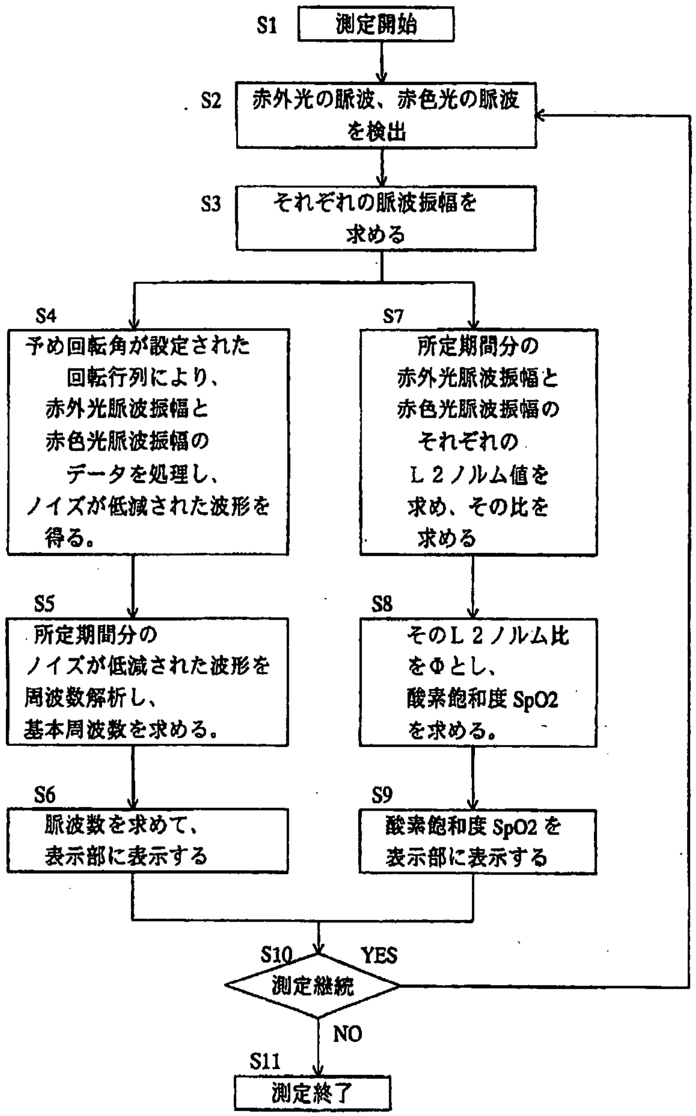
【図５】 Fig. 5


After rotated
Relative amplitude
Time [sec]
X1
X2
1.5
1
0.5
0
-0.5
-1
0
1
2
3
4
5
6
7
8
9

【図６】 Fig. 6



【図７】 Fig. 7



S1: start measurement

S2: detect pulse wave signals pertaining to infrared light and red light

S3: obtain amplitude of each pulse wave signal

S4: obtain noise-reduced waveform by processing respective pulse wave data with rotating matrix (rotating angle is predetermined)

S5: obtain fundamental frequency by frequency analysis with respect to noise-reduced waveform for given time period

S6: obtain and display pulse rate in display section

S7: obtain L2 norm values from respective pulse wave signals of given time period and obtain ratio thereof

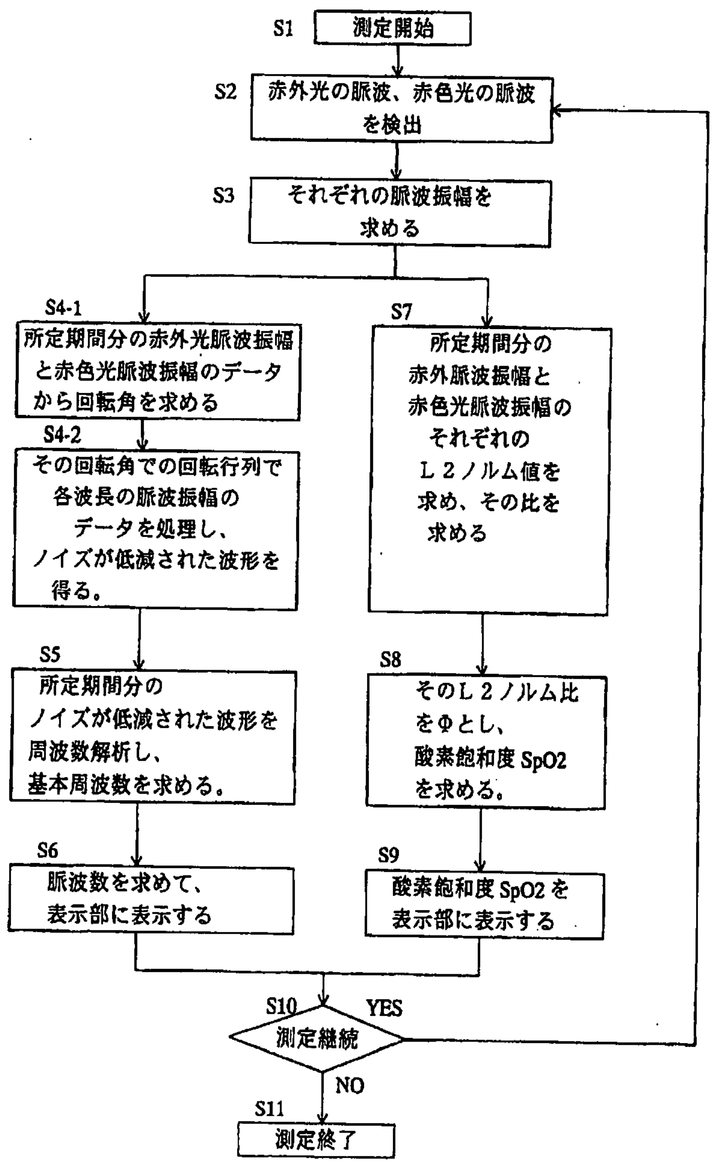
S8: obtain oxygen saturation SpO2 from L2 norm ratio as Φ

S9: display oxygen saturation SpO2 in display section

S10: measurement is continued?

S11: terminate measurement

【図８】 Fig. 8



S1: start measurement

S2: detect pulse wave signals pertaining to infrared light and red light

S3: obtain amplitude of each pulse wave signal

S4-1: obtain rotating angle from respective pulse wave data for given time period

S4-2: obtain noise-reduced waveform by processing respective pulse wave data with rotating matrix corresponding to obtained rotating angle

S5: obtain fundamental frequency by frequency analysis with respect to noise-reduced waveform for given time period

S6: obtain and display pulse rate in display section

S7: obtain L2 norm values from respective pulse wave signals of given time period and obtain ratio thereof

S8: obtain oxygen saturation SpO2 from L2 norm ratio as Φ

S9: display oxygen saturation SpO2 in display section

S10: measurement is continued?

S11: terminate measurement